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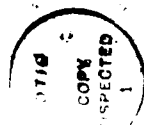
## FORMATION AND ANALYSIS OF SHALLOW ARSENIC PROFILES

*Indexing terms: Semiconductor devices and materials, Semiconductor doping, Ion implantation, Annealing*

Shallow arsenic implants were activated by furnace and rapid thermal annealing (RTA). Comparisons of junction depths measured by secondary ion mass spectrometry (SIMS) and spreading resistance (SR) showed SIMS values 50-90 nm deeper than SR values, due to ion knock-on during SIMS profiling.

As device geometries become smaller, ever shallower junctions are required for both MOS and bipolar transistors. RTA is used for shallow junction formation since it activates dopants with minimal dopant diffusion. However, accurate determination of junction depths of 150 nm or less can be difficult. In this letter we compare shallow  $n^+/p$  junctions formed by RTA and furnace annealing as measured by SIMS and SR. SIMS

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and SR were compared to determine which provides more accurate junction depths and doping profiles for high concentration, shallow junctions. Previous comparisons between SIMS and SR for furnace-annealed arsenic implants with relatively deep junctions have been made.<sup>1-2</sup> Naem and Calder<sup>3</sup> have examined shallow junctions ( $<0.2\ \mu\text{m}$ ) activated by both furnace annealing and RTA; their results will be compared to the present work.

Eleven three-wafer sets of  $10\text{--}18\ \Omega\text{cm}$   $p$ -type Si wafers were implanted with an arsenic dose of  $2 \times 10^{15}\ \text{cm}^{-2}$  at  $45\ \text{keV}$  through  $20\ \text{nm}$  of  $\text{SiO}_2$ . The wafers were annealed as shown in Table 1. The RTAs were performed using AG Associates

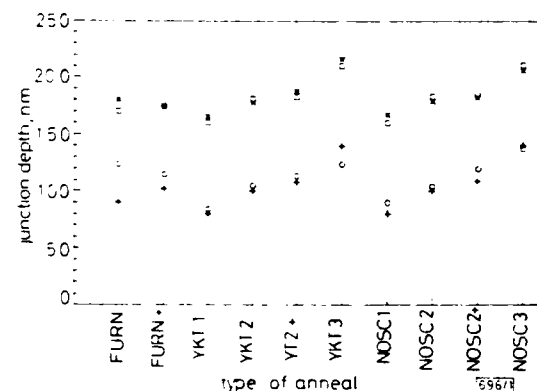
**Table 1 ANNEAL CONDITIONS FOR EACH WAFER SET**

Set	Type of anneal
FURN	15 min $900^\circ\text{C}$ furnace anneal
FURN+	15 min $900^\circ\text{C}$ , furnace anneal plus furnace processing*
YKT1	3 s $1100^\circ\text{C}$ RTA at IBM Yorktown
YKT2	10 s $1100^\circ\text{C}$ RTA at IBM Yorktown
YKT2+	10 s $1100^\circ\text{C}$ RTA at IBM Yorktown plus furnace processing
YKT3	30 s $1100^\circ\text{C}$ RTA at IBM Yorktown
NOSC1	3 s $1100^\circ\text{C}$ RTA at NOSC
NOSC2	10 s $1100^\circ\text{C}$ RTA at NOSC
NOSC2+	10 s $1100^\circ\text{C}$ RTA at NOSC plus furnace processing
NOSC3	30 s $1100^\circ\text{C}$ RTA at NOSC

\* Furnace processing: 5 min  $900^\circ\text{C}$   $n^+, p^+$  drive-in and 30 min  $800^\circ\text{C}$  LTO PSG anneal

Heatpulse 410 systems at NOSC and at IBM, Yorktown, and are labelled accordingly. Wafer sets which received further high-temperature processing to simulate normal post-implant furnace steps are labelled with a '+'. Following the anneals the  $\text{SiO}_2$  was stripped, and SR and SIMS measurements were made on each wafer. For the SR measurements, the samples were bevelled to a nominal angle of  $8^\circ$ . Bevel angles were measured by the standard dual wire image technique<sup>4</sup> and corroborated by measurement of spot separation of a laser reflected off the two surfaces; junction depth accuracy was  $\pm 20\ \text{nm}$ . For the SIMS measurements, caesium was used as the primary ion source for increased arsenic sensitivity to the mid  $10^{16}\ \text{cm}^{-3}$  range. Junction depths were estimated from the SIMS curves by a linear extrapolation of the SIMS profile down to  $10^{16}\ \text{cm}^{-3}$ .

Junction depths measured by SIMS and SR are shown in Fig. 1. SIMS gave extrapolated junction depths  $50\text{--}90\ \text{nm}$



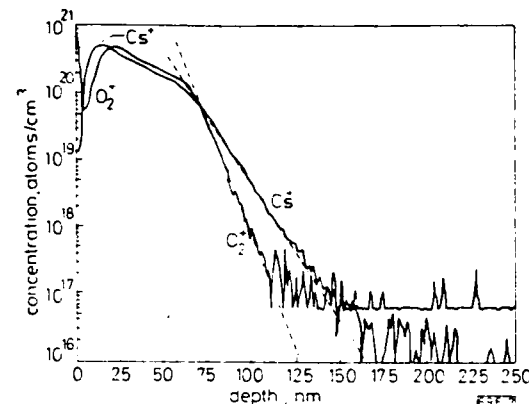
**Fig. 1 Junction depths for different processing conditions**

- × × × SIMS
- ○ ○ SR
- + + + computer model
- □ □ computer model with 25 nm/decade tail

greater than the values given by SR. Most of this discrepancy is believed to be caused by ion knock-on during SIMS profiling,<sup>5</sup> an effect increased by using caesium instead of oxygen as the sputtering ion. Ion knock-on adds a resolution tail to the SIMS profile and is mainly important for profiles with rapid concentration decreases. We observed an average slope

of  $25\ \text{nm/decade}$ , similar to the  $28\ \text{nm/decade}$  slope measured on abrupt arsenic profiles grown by molecular beam epitaxy.<sup>6</sup>

As further evidence that the observed tails are an artefact of SIMS, Fig. 2 compares profiles made using caesium and



**Fig. 2 SIMS data using  $\text{Cs}^+$  and  $\text{O}_2^+$  beams**

RTA,  $1100^\circ\text{C}$ , 3 s

oxygen beams. The junction depth measured using oxygen is  $40\ \text{nm}$  shallower than that using caesium and the slope steepens to  $14\ \text{nm}$  per decade due to reduced ion mixing. This difference in junction depth and slope was observed in all samples analysed by both caesium and oxygen profiling. While use of the lighter oxygen ion reduces arsenic knock-on, it also reduces the arsenic sensitivity of SIMS, as seen in the higher background level of the  $\text{O}_2^+$  profile.

Similar discrepancies between SIMS and SR have been noted<sup>3</sup> but have been attributed to carrier spilling in SR described by Hu.<sup>6</sup> However, extrapolations of carrier spilling to the profiles in the present work only account for at most half of the SIMS-SR discrepancy. We conclude that while carrier spilling is a factor in our SR measurements, ion knock-on in SIMS is an equal or greater contributor to the junction depths differences.

Finally, computer modelling<sup>7</sup> of these processes was used to predict junction depths for the samples. The predicted values for RTA and furnace anneals are within  $15$  and  $35\ \text{nm}$ , respectively, of the SR values (Fig. 1). Also shown are junction depth values predicted by limiting the rolloff of the computer model profiles to  $25\ \text{nm/decade}$ . These values are in good agreement with the SIMS values. Based on these results, we use the SR data for discussion of junction depths.

The three and ten second RTAs produced junction depths less than those produced by the furnace anneals. Longer RTAs caused increased junction depths. Subsequent high-temperature processing had little effect on the junction depths of the furnace annealed samples, but slightly increased them for the RTA samples.

Shallow arsenic implants were activated by conventional furnace processing and by RTA. Two techniques for measuring high concentration shallow junction depths, SIMS and SR, were compared. SIMS gave junction depth values  $50\text{--}90\ \text{nm}$  greater than those given by SR. This discrepancy is believed to be caused by the ion knock-on produced by SIMS. RTAs of  $1100^\circ\text{C}$  for ten seconds and less produced shallower junctions than furnace anneals of  $900^\circ\text{C}$  for 30 minutes.

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